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THE MEDICAL AND PUBLIC HEALTH IMPORTANCE OF THE INSECTICIDE DDT

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I FEEL it a distinct honor to be invited to appear before this distinguished group of the medical profession and on this lectureship established to revere an outstanding physician. This appearance is regarded, not as a personal recognition of any particular contribution of mine, but as an acknowledgment of the part that entomology and entomologists can play and are playing in the important and expanding field of preventive medicine.

Perhaps this occasion is another evidence of the feeling that in this day of specialization the workers in a number of related fields must join hands in a coöperative effort to elucidate many disease problems and to apply the results of such research for the welfare of humanity.

Insect-borne diseases back through the ages have been a dominant factor in determining the fate of armies and the outcome of wars. It is therefore not surprising that forward-looking medical men and engi-

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neers of the Army and Navy gave early consideration to ways of meeting the need for more effective and practical means of combating these diseases and their insect carriers. The great progress that has been made during the last few years has been interpreted by many as resulting directly from the war. There is doubt in my mind, however, whether research is more productive under the pressure of war demands than in peace. Many of the recent advances in combating insects are prewar discoveries, or are based on knowledge gathered during peacetime, as in the case of insecticidal aerosols developed by Bureau of Entomology and Plant Quarantine workers, Sullivan, Goodhue, and Fales,[1] in 1940, and methyl bromide, developed largely as an agricultural fumigant a few years prior to the war.[2] True, war makes funds available and gives special purpose to research, provides a proving ground for its findings, and accelerates the development and utilization of discoveries.

Another force that is especially operative during war is that of education. This force is probably as virile and far reaching in preventive medicine as in any other field. The incidence of insect-borne diseases, with the serious efforts put forth by military authorities to control or prevent these diseases, has been a powerful educational influence. It has brought forcefully to the attention of our millions in the armed forces and their families the importance of these diseases and the preventive measures used against them. This broad interest aroused in preventive medicine surely should not be neglected in our further efforts in health education. This enlightenment has by no means been confined to the rank and file of the armies and to the nonprofessional men of civil life. It is more or less evident at higher levels in every branch of the military service. Many medical men in uniform have, perhaps for the first time, become aware of the magnitude and importance of preventive medicine and especially of medical entomological problems. Many medical schools have modified their curricula to include medical parasitology and other subjects of vital importance in preventive medicine. Even though it will be regarded by some of you as presumptuous on the part of a layman, I venture the statement that I sincerely trust these changes will persist, and that our medical profession as a whole will give increasing attention to disease prevention rather than to thinking largely in terms of disease cure.

Of course, disease prevention is an extremely broad and intricate matter involving nutrition, housing, transportation, general economic conditions, and many fixed customs and habits, none of which are strictly medical. Responsibility in the field rests not alone on the medical profession, but involves many special groups and, in fact, the people as a whole. It is right and proper, however, that the medical profession and those working directly in preventive medicine should take aggressive leadership in research, organization, legislation, and education looking toward more rapid and general advancement of this field so vital to the people of the entire world.

Insects Important in Preventive Medicine

Insects and related arthropods rank high in importance to the health and prosperity of nations in both peace and war. Some of the world's most dreaded diseases, such as plague, epidemic typhus, and African sleeping sickness, are exclusively insect-borne. Likewise the world's most debilitating malady, malaria, is chargeable to insects. Then there is Rocky Mountain spotted fever, endemic typhus, scrub typhus, encephalomyelitis, yellow fever, dengue, relapsing fever, filariasis, kala azar, verruga, pappataci fever—a formidable array, for which insects, mites, and ticks are wholly responsible. Nor should we overlook the part played by insects in the carriage of many other diseases, such as dysentery, typhoid, and tularemia; the parasitic worms; and the trouble induced by direct attack of insects on man where no disease organism is directly involved, as in various forms of myiasis; stinging and biting pests; and those that burrow into the skin. Often worrisome forms of life, such as swarms of biting midges, mosquitoes, and fleas, may assume considerable importance in impairing efficiency and even health. The bothersome bedbug, the cockroach, the elusive flea, and the persistent chigger and seed tick, each receives its complement of profane epithets and exacts its toll of sleepless nights.

We are not inclined to associate with public health insects that carry or produce plant diseases; those that destroy vegetables or fruits, cereals, or sugarcane; or those that damage livestock or food products in storage. Yet they often are a dominant factor in decreasing food supplies, so that low-income groups, or even entire populations, suffer from malnutrition, and many die of starvation. Other effects of insects on human welfare, if not on health, are evident in the devastation of forests and grasslands, which increases the cost of suitable shelters and induces destructive soil erosion, floods, and forest fires. This by no means completes the picture, for insects feed upon our flowers and shrubs, gnaw holes in our draperies, rugs, and clothing, undermine our homes, feed upon our axe handles, and even interrupt communications by cutting down telegraph poles or burrowing through lead cables.

But insects are not all arch enemies of man. Of the some 620,000 species described, probably not more than 55,000 are recognized as being injurious. Thousands of species might be classed as neutral, and other thousands are beneficial. Some insects prey on our enemy species as parasites or predators; some contribute by destroying noxious weeds; some by breaking down dead plants and animals, so that they are returned to the soil to serve as plant food; some work over and aerate the soil; and others furnish dyes for the fine arts, fibers for clothing, or food for beneficial wildlife, our livestock and man.

In this last category the part that honeybees and other insects play in producing food often goes unrecognized. Thirty important food crops depend largely or solely upon insects to pollinate them. Without this assistance we would have to get along without such things as squash and other cucurbits, apples, sweet cherries, plums, and prunes. Furthermore, many of our crops so essential for livestock, soil improvement, and prevention of soil erosion would be barren or produce very little seed. This is true of alfalfa, the clovers, and others.

This theme is an extremely interesting and important one, and has a vital relationship to human welfare and therefore to any extensive efforts that man may put forth in combating disease-bearing and other insect enemies.

Insecticides Not the Only Weapons at Hand With Which to Fight Insects

The urge that everyone has to kill dangerous insects quickly and certainly, together with the publicity given to the insect-killing potentialities of the insecticide DDT, has diverted attention from the many other sound methods of combating insects. The enemy is so numerous, its modes of attack so diverse, and the danger of depending only on insecticides for control so grave that we must use every weapon at hand.

Only a few examples of the many ways of combating insects of medical importance other than by the use of insecticides are cited here. For mosquito control, drainage and other steps to eliminate breeding places are familiar examples. As is well known, elimination of manure piles and accumulations of fermenting vegetable matter is far more important in combating houseflies and stableflies than the use of any sort of insecticide. Certain kinds of ticks can be controlled, or even eradicated, by the destruction or manipulation of their animal hosts.

Insecticides a Direct and Quick Weapon

In combating insect pests the use of insecticides has a strong popular appeal. We are loath to take action till the enemy is upon us, and by that time something drastic must be done. It is therefore fortunate that we have a number of dependable insecticides that may be called into play on short notice.

Our insecticide arsenal was badly affected by the war. Possible war needs for arsenic and demands for lead threatened for a time one of our major groups of weapons, the arsenicals. Copper demands depleted our supply of paris green and copper fungicides, shipping interference and adverse weather reduced supplies of vital military and household insecticides made from Kenya-grown pyrethrum flowers, and the Japanese soon took over Malaya and other oriental areas from which had come our major supply of derris, one of the plants from which the highly effective rotenone is derived. The reduction in pyrethrum combined with increased military demands was particularly trying because farmers had come to depend on this insecticide for controlling many pests of vegetable crops on which arsenicals and other materials dangerous to man could not be used safely. Furthermore, it left our householders and food handlers without ammunition in the spray gun, a device now found on almost every kitchen and store shelf. The Bureau of Entomology and Plant Quarantine and many other official and private groups not only put forth efforts to increase the culture of pyrethrum and rotenone-bearing plants on this hemisphere, but instituted a search for suitable substitutes for critical or scarce insecticides. Hundreds of synthetic organic compounds were tested against a number of insects. Some showed promise, but most compounds of this class have been found to be rather highly specific. Investigations were also pressed forward on synergists, i.e., materials that would accelerate or intensify the insect killing properties of compounds having insecticidal value. These investigations too have yielded worthwhile results. None of the materials or combinations studied, however, appear to equal the organic chemical, DDT as an all-round insecticide.

DDT an Outstanding Discovery

The common name DDT is based on the generic chemical name dichloro-diphenyl-trichloroethane, but more accurately designated by the long chemical name 1-trichloro-2, 2-bis (*p*-chlorophenyl) ethane (formerly called 2, 2-bis (*p*-chlorophenyl)-1, 1, 1-trichloroethane). This compound was first synthesized by a German student, Othmar Zeidler, in 1874.[3] Like thousands of other materials synthesized at universities, it remained on the shelves as just another compound until the Swiss firm of J. R. Geigy, A.-G., in its search for mothproofing agents tested many compounds and among them DDT, which displayed distinct insecticidal value. Wiesmann of the Swiss Agricultural Experiment Station, in coöperation with this firm showed it to have merit in combating certain agricultural pests[4] and in killing houseflies.[5] Late in 1942 a sample of the insecticide prepared by the Geigy Company, and called Gesarol Spray Insecticide, was sent by the Swiss firm to its American branch, which in turn submitted it to the United States Department of Agriculture for evaluation. A group of entomologists at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine, headed by E. F. Knipling, soon proved DDT to have a remarkable destructive effect on body lice. Research work conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development was already well organized, and a colony of thousands of vigorous lice upon which to test various materials was already established; hence the development proceeded rapidly. In the meantime the Army had placed in the hands of men taking part in the North African campaign an effective louse-destroying agent known as MYL powder, which had been developed by the same scientists. DDT, where properly applied, was found to have remarkable persistence, and was not subject to deterioration as is the case with MYL powder, the principal constituent of which is pyrethrum. Furthermore, the grave problem presented by the shortage of pyrethrum appeared to have been solved.

Initial tests with DDT were conducted with caution, since the material appeared to be a nerve poison and it was suspected that possibly Germany had permitted the material to be shipped out of Switzerland in the hope that it might be used extensively on our troops and thus in some way adversely affect them. Extensive toxicological tests carried out by the Food and Drug Administration and the National Institute of Health, however, failed to demonstrate any toxic effects from the use of a powder containing 10 per cent of DDT in the neutral carrier pyrophyllite. Accordingly, after rather extensive field trials involving civilians, troops, and prisoners, DDT powder was accepted for general military use against lice.

It was found that DDT used as a powder on the skin and garments would give protection against louse infestations for three weeks or longer. This material in the form of an emulsion could also be incorporated in the garments and fixed so firmly that it would not lose its insecticidal effect for periods as long as eight weeks even though the garments were washed at weekly intervals.

Extensive field trials of DDT were carried out by medical and sanitary officers in coöperation with the United States Typhus Commission, the Rockefeller Foundation, and local civilian agencies in North Africa. The difficulty of requiring people with various prejudices and religious beliefs to remove their clothing for treatment was met by the development of a simple dusting apparatus by which the powder could be introduced beneath the clothing.[6] The proof of the efficacy of DDT in controlling an epidemic of typhus was soon forthcoming. The stage was set in Naples for a devastating sweep of the disease through the civilian population, which would undoubtedly have involved our troops. The epic curbing of this outbreak has been recounted on previous occasions. The effective organization set-up and the availability of ample supplies of DDT, which was applied to more than a million and a quarter persons in a few months, can be credited with this amazing result.

Some indication of the wide interest in DDT is shown by the tremendous number of articles on the subject that have appeared in print in the last 2 or 3 years. A survey of the literature by R. C. Roark has shown that about 600 articles have been published.[7,8]

Chemistry and Manufacture of DDT

The original method of manufacturing DDT has been set forth briefly in a British patent assigned to J. R. Geigy, A.-G.[9]:

"225 parts of chlorobenzene are mixed with 147 parts of chloral or the corresponding amount of chloralhydrate and then 1000 parts of sulphuric acid monohydrate are added. Whilst stirring well the temperature rises to 60°C. and then sinks slowly down to room temperature, the mass then containing solid parts. It is poured into a great deal of water, whereupon the product separates in solid form. It is well washed and crystallized from ethyl alcohol forming fine white crystals, having a weak fruit-like odour."

Results of early tests in this country with DDT were so promising that the chemical industry was encouraged to go into production as rapidly as possible, and every effort was put forth to make adequate supplies available to the military. The material was placed under allocation by the War Production Board on January 1, 1944 (Order No. M-340). However, as production was increased, new and more extended uses were found which continued to keep military demands ahead of production. At present about a dozen chemical firms are producing this insecticide and, with the exception of relatively small quantities that are devoted to research, the entire supply of approximately 2,000,000 pounds per month is going into military uses.

Technical DDT consists largely of the para-pará isomer of dichlorodiphenyltrichloroethane, which some of the ortho-pará isomer and ten of twelve other compounds. The para-pará isomer is the most highly insecticidal and constitutes about 70 per cent of the technical material, the ortho-pará isomer makes up about 25 per cent, and the other compounds the remaining 5 per cent. The refined or recrystallized product consists almost wholly of the para-para' isomer and is designed as pure DDT. This pure compound melts at 108.5° to 109°C. The technical product has a melting range of about 25°; therefore, specifications covering purchases for military uses designate a setting point rather than a melting point. It is set at not less than 88°C. A number of compounds containing DDT have been put out by commercial concerns under various trade names, such as Gesarol and Neocid.

DDT is practically insoluble in water, but dissolves readily in a number of organic solvents such as xylene, acetone, and chloroform. Petroleum oils also dissolve varying amounts of DDT; the less refined these oils are, the greater is their solvent power. Ordinary kerosene will dissolve approximately 5 per cent of DDT at room temperatures.

For general insecticidal uses there is no need to consider material of high purity and thus add to the cost of production. For special purposes, such as for incorporation in aerosol bombs, the use of refined DDT may be justified in order to minimize corrosive action on the containers.

The investigations in the Bureau of Entomology and Plant Quarantine of the chemical make-up of technical DDT have yielded important information.[10] Research chemists in the Bureau[11] have also developed a colorimetric method by which minute quantities of DDT can be determined which permits a more accurate evaluation of the residue problems such as on food and forage plants and in water.

Formulations of DDT

To get the highest insecticidal efficiency from any material it must be properly formulated to fit into the many conditions encountered. DDT has been prepared in various mixtures as dusts, sprays, and aerosols, but much remains to be done in this field. As has been stated, the simple mixture of finely ground DDT in pyrophyllite was first used in the field of medical entomology. Since that initial step, many formulations have been prepared for diverse uses against insects of medical, veterinary, and agricultural importance. These formulations involve numerous solvents, wetting agents, emulsifiers, and stickers, and various combinations including mixtures with other insecticides. Proper formulation of insecticides not only makes them more effective, but also ideally at least, more economical, more convenient to ship and store, more easily applied, and less likely to have an adverse effect on men, animals and plants.

Fortunately, for two of the major uses DDT can be very cheaply and easily prepared. I refer to the dust mixture already mentioned for louse control and to kerosene or fuel-oil solutions for use as a mosquito larvicide. Some difficulty has been experienced, however, with the DDT crystallizing out in the oil drums when the material is stored at low temperatures. Since these crystals are not easily redissolved, it is desirable to add an auxiliary solvent, such as xylene or a heavier petroleum fraction.

When the carriers employed in the sprays evaporate, beautiful crystals of DDT are left on the surface of sprayed objects. The type of these crystals varies much with the carrier used, as does also the rapidity with which they are formed. There is evidence that the type of crystalline deposit affects its insecticidal potency.

Methods of Application

Naturally, methods of applying insecticides must be governed by the nature of the problem. The stability, solubility, residual effect, and other characteristics of DDT make possible the use of many different methods of application and have suggested almost innumerable types of apparatus for dispersing it. These range from the simple hand dusting, as in control of lice on man, to the application to jungle areas, by huge aircraft, of dusts, sprays, and aerosols for mosquito control. They also include impregnation of clothing and other fabrics in an emulsion or solution; the employment of explosives in various devices, of special generators to produce thermal aerosols, of manually-operated aerosol containers with liquefied gas as a propellent, of atomizers of diverse types and sizes (some little larger than a fountain pen), of various types of sprayers and dusters; and even the use of an oil can or a paint brush. Automatic drip cans or impregnated sawdust or other material have also been used for treating mosquito-breeding rice fields, streams, and ponds.

Most of these dispersal devices are in an experimental stage, and no doubt many new ones will be devised. It is a fertile field for those with inventive abilities. Through all the experimental and practical work the need has been apparent for special distributing equipment to meet the diverse conditions encountered in military operations and those more fully recognized here at home.

The development of methods for aerial application has been and still is of absorbing interest. Since 1922, when the Bureau of Entomology and Plant Quarantine first experimented with airplane dusting of calcium arsenate for control of the boll weevil on cotton, little attention has been devoted to spraying devices. The high toxicity of DDT to many insects gives us, for the first time, a liquid material that can be economically applied from the air. The Husman-Longcoy equipment for use on a Cub plane has proved useful and a basis for the development of other equipment, especially for employment on larger fast-flying craft. Tests have run the gamut from the Cub to large bombers and from tanks holding 35 gallons to those holding 500 or more. The helicopter, autogiro, and dirigible have not been forgotten. Prior to this work little information was available upon which to base even a guess on the effect of speed, type of plane, place and character of discharge, and other factors influencing the break-up of liquids. Droplet size is a highly important item in insecticidal efficiency which we must watch.

Toxicology

One of the first points considered in connection with the development of a new insecticide is its toxicity to man and higher animals, as well as to various lower forms of life beneficial to man. Therefore, as soon as the marked insecticidal value of DDT was determined at the Orlando laboratory, steps were taken to have its toxicological effect investigated by Dr. Herbert O. Calvery and his associates in the Food and Drug Administration and Dr. Paul A. Neal, of the National Institute of Health. Later, Dr. Robert A. Kehoe, of the Kettering Institute of the University of Cincinnati, and Dr. M. I. Smith, of the National Institute of Health, undertook supplementary work.

Some of the results of this excellent research have been published,[12-16] and no attempt will be made here to review them in detail. There is complete agreement among these workers that DDT acts as a nerve poison when ingested or absorbed, that its toxicity to different warm-blooded animals varies widely, but that its acute toxicity orally is not of a high order. For instance, the oral LD 50 (median lethal dose) for white rats ranges from 200 to 300 mg. per kilogram of body weight, depending on size and age; for rabbits about 500; for dogs about 200; and for mice about 400. In preliminary experiments carried out by Orr and Mott,[17] horses and sheep showed no clinical evidence of poisoning when given DDT by mouth in doses of 100 to 200 mg. per kilogram repeated for several days. Sheep were given ½ to 2 grams per kilogram of body weight as a single dose. The largest dose caused tremors for one day and loss of appetite for two or three days. Some cows showed tremors after the first feeding of 100 mg. per kilogram but recovered even when the dose was increased after a week to 150 mg. and after another week to 200 mg. Some of these animals when posted showed hemorrhagic spots on the heart and other viscera. These spots apparently disappear after a few weeks. It is characteristic of DDT poisoning that animals may develop tremors from daily doses, but that these may entirely clear up while the administration is being continued at the same level.

It was determined early by Dr. Calvery that no toxicity or irritation results from 10 per cent of DDT in pyrophyllite applied as a dust to the skin. This has been amply demonstrated by the free use of the powder by hundreds of thousands of troops and civilians in louse control. DDT in solution, however, can be absorbed through the skin. This is particularly true of oil solutions. There was some fear that DDT solutions might prove toxic when used as sprays, and especially as aerosols but extensive tests by the National Institute of Health showed that animals exposed to very heavy doses in strengths adequate to kill insects produced no ill effects if the animals were not allowed to lick the insecticides from their bodies.

Preliminary experiments indicate that DDT is rather poisonous to poultry and birds. Investigations being conducted by the Fish and Wildlife Service indicate that birds are more tolerant of DDT than mammals and that wild duck are especially resistant, but that snakes, salamanders, toads, and frogs may be killed by dosages in the upper range of insecticidal efficiency. Unfortunately, fish are markedly susceptible. This appears to be especially true of trout, and it is possible that they may be injured by feeding on insects dropping into the water after being killed by DDT. Apparently DDT is most toxic to fish when applied in colloidal suspension in water, with emulsion next, and surface applications of dusts and oil solutions least poisonous to them.

The chronic toxicity of DDT in various forms has not been fully evaluated; although relatively large daily doses can be tolerated over long periods, there is evidence of some cumulative effect and of slight sensitization in animals but not in man.

It may be concluded from available facts that DDT is much less dangerous to man and higher animals from direct toxic action than are many other insecticides, but it should be handled with care, especially to avoid ingestion and prolonged contact of oil solutions with the skin.

Among the insects there is a wide range of susceptibility. DDT kills both by contact and as a stomach poison. Some insects, such as the Mexican bean beetle and boll weevil are little affected by it when applied in practical doses. On the other hand, extremely minute quantities picked up by flies crawling over a surface sprayed months before will effect a kill, and as little as 1 part of DDT to 100 million parts of water will destroy certain mosquito larvae in the laboratory. Recent work by the Bureau of Entomology and Plant Quarantine indicate that 1 gamma (one-millionth of a gram) will kill a housefly.

Part Played by DDT in the War

There have been in circulation so many statements about DDT and its insect-killing powers that it is logical to ask—just what is DDT doing toward winning the war? It seems unnecessary to dwell on the importance of insects as annoyers and disease carriers in large-scale military operations. History is replete with evidence of this. Napoleon's operations in the West Indies were definitely stopped and the whole history of that area, and perhaps of the United States, was changed by the yellow-fever mosquito, which killed more than three-fourths of his army. Louse-borne typhus and malaria have determined the outcome of many campaigns; likewise, fly-carried dysentery and typhoid have seriously interfered with many military operations and caused much suffering, as happened in our Spanish-American War.

The world-wide struggle in which we are now engaged has given opportunity for every insect-transmitted malady to attack naturally nonimmune groups of men. Furthermore, fast transport, especially by air, makes possible the movement in a few hours of infected personnel and infected insects from continent to continent and from hemisphere to hemisphere. To cope with this situation the best entomological and chemical knowledge, the soundest medical judgment, and the highest engineering skill are demanded. The promptness with which threatening outbreaks have been quelled and the present low incidence of these diseases among our vast armies speak for the effectiveness with which these forces have been brought to bear on disease problems.

The success of the campaign against the typhus outbreak in Naples during the winter of 1943-44 was due almost wholly to this new insecticide. It would not be fair, however, to ascribe to DDT more than its rightful share of the credit for these remarkable results. Recognition must be given also to the highly effective organization and vigorous and persistent efforts of the Typhus Commission, the Medical Corps of the Army, the Public Health Service, the Rockefeller Foundation, and other agencies concerned. Nor should we forget the quiet, indefatigable researchers of the Orlando laboratory of the Bureau of Entomology and Plant Quarantine, who made this effective weapon ready for just such an emergency. Obviously, without a sound organization, appropriate educational work, and full coöperation, including that of line officers and the entire military personnel, it would have been impossible to set up delousing stations, each capable of treating 5,000 persons a day, and to round up from their underground habitations and delouse the families of Italians. More than a million and a quarter persons were treated during that winter, and owing to the louse powder, supplemented with methyl bromide fumigation, practically no cases of typhus have occurred among our forces. The introduction into this country of lice and louse-borne diseases with prisoners of war, refugees, and returning troops, has also been prevented. The armies of Great Britain are also making use of DDT against lice, both as a powder and as a clothing impregnant.

Mosquito control is a major factor in the prevention of malaria, dengue, filariasis, encephalitis, and yellow fever, and DDT is coming to play a major role in combating these diseases in our war operations. True, drugs are of recognized value in suppressing and treating malaria, but no drug has yet been found that is a true preventive or a dependable cure. For yellow fever we have a preventive vaccine that gives our troops protection, but there are multitudes of susceptible people, both in this country and in other parts of the world, who are not vaccinated, and we must depend upon fighting mosquito carriers, especially on aircraft and around airports, if we are to hold this dread disease at its present insignificant level. As for the other diseases mentioned, there is no known method of prevention other than through mosquito control.

Thus far DDT has been employed in only a minor way in the antimosquito work of the military, and not at all by civilians. It is commencing to strengthen our aggressive war on mosquito breeding in training centers in this country and in camps in stabilized areas. Its greatest usefulness, however, is in ridding beachheads of infected mosquitoes—in fact, all mosquitoes—at the critical landing period when head and bed nets and other mechanical protection cannot be used and usual antilarval measures cannot be employed. It seems almost incredible that on D-day a few sweeps of a fleet of bombers with an almost invisible discharge of DDT in oil can destroy practically every mosquito in the area and permit our forces to concentrate on the Japs without danger of malaria or dengue infections for at least several days.

As little as 1/10 pound of DDT per acre has been shown by the entomologists at Orlando to kill all larvae of the common malaria mosquito, *Anopheles quadrimaculatus* Say, under favorable field conditions. An application of 1 quart of oil containing 5 per cent of DDT to the acre, under ordinary conditions of vegetation, will kill all larvae of this species. Even under jungle conditions 3 quarts of this solution per acre, if broken into fine spray particles 20 to 200 microns in diameter, will kill more than 95 per cent of all mosquitoes, both larvae and adults in the area. Dusts containing 10 per cent of DDT used at the rate of 1 to 2 pounds per acre gave a complete kill and reduced breeding for one to two weeks in moderate vegetation and longer in heavy vegetation. Wind and wave action soon terminate the residual killing effect of both dusts and oil solutions. In xylene emulsions DDT can be prepared and shipped in concentrated form and diluted with water as used. Such emulsions were effective against *Anopheles* and several species of culicine larvae in dilutions as low as 1 part to 20 million. As little as 1 part per million had a lasting larvicidal effect in rain barrels.

As yet DDT has not been employed in insecticidal aerosols in field operations. However, experimental work carried out by the Bureau of Entomology and Plant Quarantine both at Orlando and at the Beltsville Research Center, has shown that the addition of 3 per cent of DDT materially increases the effectiveness of the pyrethrum aerosol at the strength now used against mosquitoes, and against flies its killing power is greatly enhanced.

One of the most remarkable qualities of DDT as an insecticide is its persistence or residual effect. This characteristic may be the one that will give us the whip hand in malaria control. When DDT in solution or emulsion is applied to wood or canvas as a medium fine spray at the rate of 200 mg. per square foot of surface, mosquitoes resting on such surfaces are killed in a few hours. This killing effect persists for several months. Its persistence is even more striking in the case of flies. It is possible to spray fences, buildings, and even vegetation around fly breeding places, and expect the flies to be killed as they emerge from their puparia and crawl upon such objects. The insects are excited after they have rested on treated surfaces for a short time, but even though they may fly away most of them succumb. Most mosquitoes normally rest on nearby objects for at least a short time after becoming engorged with blood. Some fly about and alight several times while they are seeking a blood meal. In sprayed rooms or tents this would appear to insure contact of the insects with the DDT crystals and resultant death before the completion of development within their bodies and introduction into susceptible hosts of the organisms of malaria, yellow fever, dengue, or filariasis.

The fly problem has been acute in a number of the war theatres. This was particularly true in North Africa and on some of the islands of the central and southwest Pacific. In the African operations houseflies were mainly involved. In the Pacific blowflies have been most troublesome. Unfortunately, DDT was not available during the North African campaign, but it is now meeting an urgent need in the Pacific theatre. DDT sprayed from the air has done much to remove the hazards of fly-borne dysentery and annoyance from flies during landing operations. Applications from the air, supplemented by the spraying of tents, buildings, latrines, and equipment, and by the usual sanitary and other fly-control procedures, hold the fly population to a minimum.

The residual effect of DDT is particularly useful in combating flies. This was first brought out by Wiesmann's work in Switzerland.[5] Concurrent work by the Bureau of Entomology and Plant Quarantine in this country,[18,19] showed that 5 per cent of DDT in kerosene applied to wood surfaces in buildings would remain highly toxic to houseflies for four to six months, and that aqueous emulsions were equally effective. The type of surface, the presence of oils or grease and dust in the air, and other factors influence the duration of effectiveness. Incorporation of DDT in paints and varnishes holds little promise, but the material retains considerable killing power when applied in cold-water paints.

The excreta of animals to which DDT has been fed kills flies crawling over it and prevents maggot growth. DDT has also shown some possibilities for treating manure to prevent fly breeding.

DDT is remarkably effective against fleas, either on animal hosts or on the soil or floors upon which they develop. This effectiveness has been shown for the common cat and dog fleas, the Indian rat flea, the sticktight flea, and others. Some preliminary tests indicate that fleas on rats can be destroyed by spraying or dusting the rat runs with DDT formulations.

Although bedbugs are of little importance in disease transmission, their indirect effect on human efficiency through annoyance and loss of sleep is recognized. The effectiveness of DDT against these disgusting pests is almost unbelievable. A 5 per cent solution of DDT in refined kerosene, applied as a spray to infested beds and mattresses, not only kills the bugs actually struck but also persists for six or eight months so that any bugs coming in contact with the sprayed surfaces are killed.[20]

Another group of insects that play a small part in disease distribution are the cockroaches. The action of DDT against these pests is not so spectacular, but it is distinctly toxic to them. Work thus far indicates, however, that the standard sodium fluoride treatment or pyrethrum as a contact spray is more effective.

Ticks, almost down to the last species, may be considered potential disease carriers. Several species are especially to be condemned, since they carry such deadly diseases as Rocky Mountain spotted fever, tularemia, and relapsing fever, produce paralytic conditions, and in many instances sorely annoy and cause secondary infection through their irritating bites. In experimental work carried out by Gouck and Smith[21] 5 per cent of DDT in aqueous emulsions was effective against various stages of the brown dog tick and larvae of the lone star tick on dogs, and emulsions containing 0.5 per cent of DDT sprayed on infested roadside vegetation gave a high degree of control of adults of the black-legged tick for at least three weeks.

Preliminary experiments with DDT in kerosene or fuel oil applied as a spray to areas infested with the sand fly (*Culicoides*) and the blackfly appeared to eliminate the adults for at least a few days. Such solutions painted on window screens also prevented the sand flies from entering.

Chiggers and other mites claim our attention by their transmission of scrub typhus and by the extreme itching of their toxic bites. Numerous fever and other systemic reactions occur, and severe secondary infections are frequent. DDT promises to be valuable in combating these pests.

What Does the Future Hold?

Peacetime developments have been adapted quickly to war needs, and we must be as alert in turning the implements of war to postwar problems. Fortunately, in the field of clinical medicine practically all the equipment, drugs, and surgical techniques that are emanating from the war effort can be applied at once in peace time. This is almost as true in preventive medicine, though the adaptation may come more slowly.

Since the interest of both physicians and laymen in preventive medicine is now far more general than before the war, can we not grasp this opportunity to extend research in the causation and prevention of disease and to further the application of acquired knowledge in this field?

Are we as physicians, sanitarians, engineers, entomologists, and economists to be content with the dynamite of plague hidden in our western yard, with the presence in our South of myriads of pestiferous yellow-fever mosquitoes ready to scatter the dread black vomit and the pain of breakbone fever over our land? Are we to continue to condone the presence of millions of rats in our cities and villages, and on our farms, permitting them to harvest the fruits of our labor and, with their associates the fleas and mites, to debilitate our people with endemic typhus? How long are we to harbor among the poor, and too often among the affluent as well, the disgusting louse? We know that these parasites have brought death to millions, that they attack man exclusively, and that they cannot survive without our blood and the warmth of our bodies. We now know also that a single treatment of every infested person with DDT would eliminate these lice from the earth. Should we be content to look on complaisantly while emaciated millions drag their malaria-shackled bodies from neglected fields to tottering huts? These problems are a challenge to the world that must be accepted. I do not mean to depreciate the excellent work that has been done, but the urge is on us and in the immediate postwar period it would seem both desirable and necessary to quicken our efforts.

After the fall of Germany and Japan we will still be confronted with armies of dangerous insect enemies which in the long run may cause more suffering and death and economic losses than our present human foes. In this war on the insects DDT will, I am confident, occupy a leading place in the arsenal we must keep ever ready to meet their varied forms and diverse methods of attack.

Modern transportation makes all countries of the world close neighbors. Therefore, one of our first and continuing problems is to prevent the spread of dangerous insects and the diseases they carry. In this field DDT and pyrethrum aerosols and sprays, if properly applied in aircraft, ships, and trains, will do much to minimize this hazard. The insect-control work around hospitals housing returned veterans, as well as educational work, should go far in preventing any serious outbreaks of insect-borne diseases. The extended antimalaria program proposed by the United States Public Health Service in coöperation with State health authorities should further aid in preventing the introduction and spread of mosquito-carried maladies. It would also be taking the first long step toward that ambitious program suggested by Dr. L. L. Williams, Jr. of eradicating malaria from this country. In this program DDT, especially in the form of a residual spray, will be a major weapon.

It is difficult to foresee the precise place that DDT may assume in the future. In addition to the fields of application briefly mentioned above, one can visualize farms with contented livestock and cleaner dairy products through the use of DDT against hornflies, stableflies, and houseflies; also outing areas with less annoyance from punkies or sand flies (*Culicoides*), blackflies, and mosquitoes. Insect destroyers of crops may be held in stricter control, thus helping to assure ample and economic food production which in turn means better general health and happiness.

DDT appears destined to assume an important role in controlling sand flies (*Phlebotomus*) and thus reducing the incidence of kala azar and sand fly fever. Likewise, through its use against these insects, the dread disease verruga may be controlled in Peru and Colombia. Tick control will probably be materially accelerated by the use of DDT, and this material will doubtless find an expanded field of usefulness in combating flies of all kinds. The Chagas disease situation in the Americas may be materially helped by the availability of DDT in postwar days and its employment against the kissing bugs that transmit that malady. The persistence of this insecticide on vegetation suggests the possibility of its successful use against the dread sleeping sickness of Africa, as well as the persistent and infection-carrying eye gnats in various parts of the world. This would mean a great boon to the peoples in many lands where chronic conjunctivitis, trachoma, and resulting blindness are so prevalent.

Due regard must be had for the detrimental effect of DDT on beneficial insects and other forms of life when its widespread application is contemplated. We must learn more about the general field of usefulness of DDT as an insecticide, and especially about its limitations. Much remains to be done in the perfecting of formulas for diverse uses and methods and equipment for application.

General James S. Simmons, of the Surgeon General's Office, United States Army, has summed up his views on DDT as follows: "I feel quite sure that the knowledge gained of this amazing chemical, constitutes the most valuable single contribution of our wartime medical research to the future health and welfare, not only of this nation, but of the world."[22] Magic insect killer though DDT is, it must be applied by the right method, in the right form, and at the right time. Many writers have claimed too much for DDT. It is not a panacea for all insect ills, but it should hold an important place in the preventive medicine of the future.

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